Influence of uplink limitation and broadcast traffic on power efficiency in long-reach optical access network

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ABSTRACT

Different optical access technologies are studied with respect to their power efficiency. Considered networks provide long-reach optical access. A network model that includes various network and energy related parameters has been developed. The influence of uplink capacity limitation and the amount of broadcast downstream traffic on power efficiency is evaluated within the network model. Long-reach passive optical networks provide the best power efficiency.

Keywords: Long-reach optical access network, energy efficiency, power consumption, broadcast

1. INTRODUCTION

1.1 Current trends in access networks

Recent studies show permanent growth of both Internet traffic and number of broadband subscribers worldwide. The total number of broadband subscriber has increased from 200 millions to 730 millions in four years, from 2005 to 2009 [1]. These trends are related to more intensive Internet usage and to emerging high-speed bandwidth-hungry applications. Quadruple-play services (convergence of VoIP, HD TV, data and wireless access possibility) are an important contribution to the increasing bandwidth demand and growth of access networks. In order to run high capacity access networks which can provide such services to users, more and more electrical power is needed. Driven by the goal to reduce energy-related operational expenditure (OPEX) and to follow the trend of green networks, power consumption of network equipment has become an important issue. Today, research about power consumption in the access area focuses on optical techniques because it has been shown that they are more power efficient than their copper or wireless counterparts [2].

1.2 Considered access network options

This work concentrates solely on optical access. We considered in this study two access topologies, namely point-to-point (P-t-P) and point to multipoint (P-t-MP). P-t-P systems are implemented using direct connections between the CO and customer premises equipment (CPE) through 1 Gbit/s or 10 Gbit/s Ethernet links. For P-t-MP systems, we considered Gigabit passive optical network (GPON) specified by the ITU-T as well as Ethernet PON (1G-EPON) and 10 Gbit/s Ethernet PON (10G-EPON), which are standardized by the IEEE. Both 10G-EPON options, namely the symmetric, i.e., 10 Gbit/s in downstream and 10 Gbit/s in upstream, and the asymmetric, i.e., 10 Gbit/s in downstream and 1 Gbit/s in upstream, are included in the study. The considered optical access technologies are referred to as fiber-to-the-home (FTTH) networks. Moreover, the mentioned FTTH networks are modeled with additional amplifiers that represent network element needed for reach-extension. Thus, all considered access networks are so called long-reach options.

2. DESCRIPTION OF THE MODEL

2.1 Model-relevant parameters

In our study, the power efficiency of different extended-reach optical access networks, especially long-reach PONs, with a focus on the amount of broadcast traffic and uplink limitation in the central office is analyzed. We estimate the power efficiency of the whole network by taking into account all contributing elements and peculiarities of each technology, such as topology, maximum reach, typical configuration and realization, and maximum data rates in downstream (DS) and upstream (US), see Table 1.

The entire network model includes several modules, as shown in Figure 1. The network elements are modeled at the chip level. Their structure is defined as the composition of main power-consuming functional blocks. The power consumption of the considered components is taken from a data base, which we created by studying various product data sheets and research papers. Thus, first generic structures for both network-side and user-side elements are specified and then their total power consumption is calculated by summing up values for consumption of individual functional blocks. Other parameters that define our network model can be described as configuration and network-related parameters. Configuration parameters include number of users per central office, uplink capacity (C_U), and the bandwidth required for broadcast (B). Network-related parameters are firstly the network-specific topology and maximum reach as well as the power consumption of the corresponding network elements, and secondly the maximum upstream and downstream data rates per user that are directly influenced by the applied network configuration and its parameters. The combination of the mentioned factors and their values represent the input to the model used for calculation of power efficiency. The output of the model is power efficiency obtained from the power consumption values of the whole network and the resulting achievable data rates per user. Thus, the resulting power efficiency is expressed in Watt per user per bit/s of user's data rate.

Table 1. Maximum data rates (downstream: r_{DS} and upstream: r_{US}) of considered access networks and percentage of DS bandwidth considered for broadcast traffic in our model

Access Network	r_{DS} [Gbit/s]	r_{US} [Gbit/s]	$B = 50$ [Mbit/s]	$B = 500$ [Mbit/s]
			$B_{\%} = (B/r_{DS}) \cdot 100\%$	
1G P-t-P	1	1	5%	50%
EPON	1	1	5%	50%
WDM PON	1	1	5%	50%
GPON	2.3	1	2.2%	21.7%
10G P-t-P	10	10	0.5%	5%
10G-EPON (10G/1G)	10	1	0.5%	5%
10G-EPON (10G/10G)	10	10	0.5%	5%

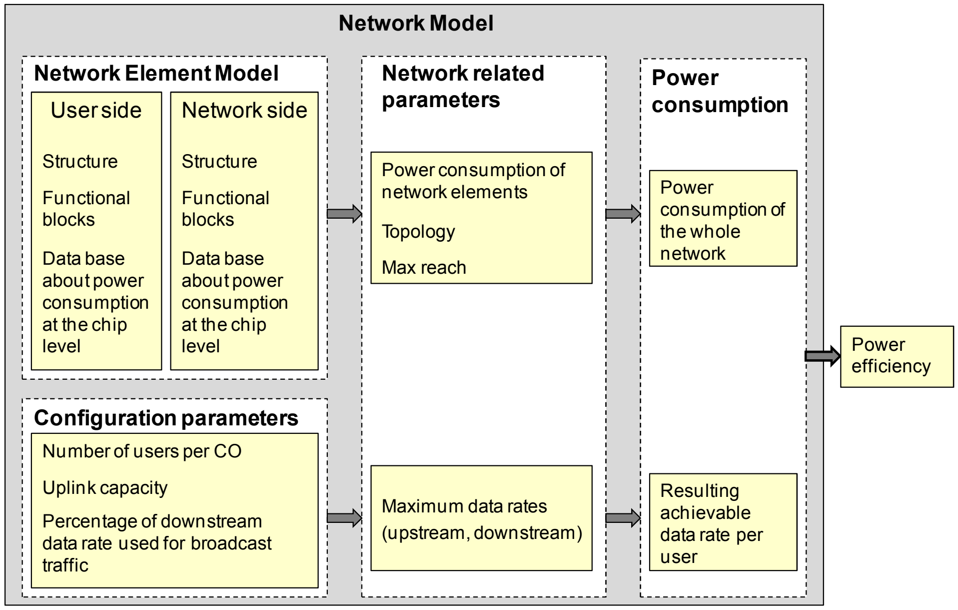

Figure 1. Description of the considered network model composition

2.2 Mathematical description

Network users that are served with a P-t-P Ethernet connection are able to exploit their dedicated data rates per line up to the maximum. But due to the fact that users of passive optical networks connected to the same OLT have to share both US and DS data rates, they can not reach the maximum data rates (r_{DS} and r_{US}) listed in Table 1 unless there is only one user per OLT. Thus, the average data rate per user (R_U) for PONs is calculated according to the three cases as described in Table 2, in Equations (1)-(3). When the first condition is satisfied, i.e., when $C_U > N_{OLT} \cdot (r_{US} + r_{DS})$, the total bandwidth consumed by all active users is below the given limit, C_U, so that all users can be provided with the maximum data rates in both upstream and downstream directions. The second condition reflects the case when the bandwidth limitation is reached, but there is still no effect on the broadcast traffic, i.e., when $C_U < N_{OLT} \cdot (r_{US} + r_{DS})$ and $\frac{C_U - N_{OLT} \cdot r_{US,L}}{N_{OLT}} > r_{DS} \cdot B_{\%}$. In this case, both downstream and upstream data rates are reduced, but not as much to affect delivering of broadcast services. Finally, the third condition refers to a strong reduction in the available bandwidth per user due to the uplink limitation, where not only the best-effort but also the prioritized broadcast traffic is throttled.

Table 2. Expressions for calculating the user data rate in PONs

	R_U	Case condition	
Case 1	$r_{DS} \cdot B_{\%} + [r_{DS} \cdot (1 - B_{\%}) + r_{US}] \cdot \frac{N_{OLT}}{N_{user}}$	$C_U > N_{OLT} \cdot (r_{US} + r_{DS})$	(1)
Case 2	$r_{DS} \cdot B_{\%} + (r_{DS,L} - r_{DS} \cdot B_{\%} + r_{US,L}) \cdot \frac{N_{OLT}}{N_{user}}$	$C_U < N_{OLT} \cdot (r_{US} + r_{DS})$ and $\frac{C_U - N_{OLT} \cdot r_{US,L}}{N_{OLT}} > r_{DS} \cdot B_{\%}$	(2)
Case 3	$r_{DS,L} + r_{US,L} \cdot \frac{N_{OLT}}{N_{user}}$	$C_U < N_{OLT} \cdot (r_{US} + r_{DS})$ and $\frac{C_U - N_{OLT} \cdot r_{US,L}}{N_{OLT}} < r_{DS} \cdot B_{\%}$	(3)

We consider two values to express the limitation of C_U. The first one is 32 Gbit/s of uplink throughput, which today each central office that is able to serve 1000 users should provide, and the second one is a more future-oriented value of 320 Gbit/s.

Because of its point-to-multipoint topology, PON is a medium perfectly suited for broadcast services such TV distribution. While in P-t-P networks both broadcast and multicast traffic have to be multiplied and transmitted to users in parallel over different fibers, power-splitting PON can naturally support broadcast and multicast services by sending only a single stream to all users. This property of PON options is addressed by introducing the broadcast factor ($B_{\%}$), which represents the percentage of the downstream data rate used for broadcast services., see Table 1. $r_{DS,L}$ and $r_{US,L}$, which are described by Equations (4)-(6), represent the DS and US data rates of the networks limited by the limitation of the uplink (C_U). In the following equations

$$r_{DS,L} = \frac{C_U}{N_{OLT} \cdot \left(\frac{r_{US}}{r_{DS}} + 1\right)}, \tag{4}$$

$$r_{US,L} = \frac{C_U}{N_{OLT}} - r_{DS,L}, \tag{5}$$

and

$$\frac{C_U}{N_{OLT}} = r_{DS,L} + r_{US,L}, \tag{6}$$

N_{user} and N_{OLT} are the total number of active users connected to the CO and optical line terminals located in the CO, respectively.

In our model, we consider reach extension of access networks by means of optical amplifiers [3]. For all types of PON we consider doped fiber amplifiers, which can extend the transmission span from traditional 20 km that are specified in PON standards to 100 km. Moreover, long-reach network can provide broadband access to a number of users which is four times higher than in traditional PONs. For 1G P-t-P Ethernet connections we consider power efficient optical-electrical-optical repeaters, while for 10G P-t-P links, semiconductor optical amplifiers were taken into account.

3. RESULTS

The output of our model for power consumption estimation is shown in Figures 2 and 3. The results depict the power efficiency expressed in W/user/(Gbit/s) for up to 1000 users per CO.

The results for the scenario in which 50 Mbit/s is reserved for broadcast traffic while the central office offers an uplink capacity of 32 Gbit/s are shown in Figure 2, while the more powerful scenario in which 500 Mbit/s is used for broadcast services in a network with 320 Gbit/s of uplink capacity is shown in Figure 3. When comparing the two figures it can be seen that the optical access technologies are about 10 times more efficient in the high capacity scenario, which promises delivering broadcast content such as HD TV in a power efficient manner. P-t-P and WDM PON technologies are the most power consuming. GPON and EPON provide the same characteristics and are the most efficient because they are not influenced by the considered limitations and thus can exploit their capacities to the maximum. When looking at the curve representing 10G/10G EPON in Figure 3, one can see that the power efficiency is being reduced due to the limitations of the system for more than 500 users per CO. Above this point, the power per Gbit/s of 10G/10G EPON becomes higher which causes that the two 10G-EPON versions become equally efficient for very high numbers of users. The results are obtained under assumption that all users in the network are active and consume the maximum bandwidth provided. Power efficiency can be further improved by applying different methods for reduction of the total power consumption such as considering day/night traffic variations, utilization of low-power modes, adapting line data rates and switching off inactive equipment [4].

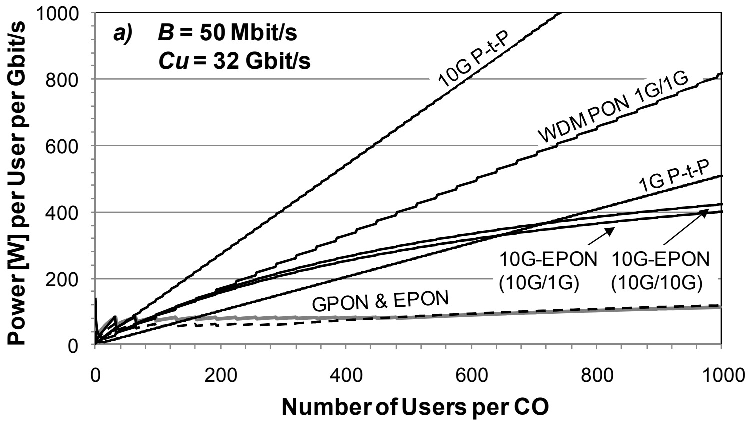

Figure 2. Results on power efficiency for C_U = 32 Gbit/s and B = 50 Mbit/s

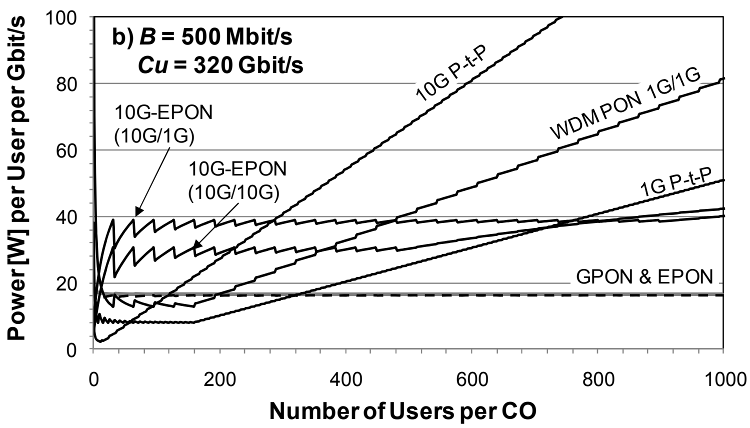

Figure 2. Results on power efficiency for C_U=320 Gbit/s and B = 500 Mbit/s

4. CONCLUSIONS

This paper gives the analysis of power efficiency of long-reach optical technologies in the access network area. A special focus was dedicated to the relation between the amount of broadcast traffic and the resulting power efficiency of the given access network. The results show that optical access networks are power efficient solutions for distribution of high-speed broadcast data. Especially PONs will be able to deliver high bandwidth reserved for TV content to many users while remaining the most energy efficient access solution for network providers.

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